

**STRUCTURAL Fe-Cr STEEL SHEET, MANUFACTURING METHOD THEREOF,
AND STRUCTURAL SHAPED STEEL**

5 BACKGROUND

1. Field of the Invention

[0001] This invention relates to structural Fe-Cr steel sheets, which have a strength equivalent to that of SS400 defined by Japanese Industrial Standard (JIS) G 3101 (1995) and which are used for civil engineering and architectural structures such as bridges and housing structures, 10 requiring superior corrosion resistance, durability, weldability, and characteristics of welded portions. More particularly, this invention relates to a structural Fe-Cr steel sheet in which variations in strength in a coil thereof does not substantially exist and in which deteriorates in the strength of welded portions does not substantially occur even when fabrication is performed by electric resistance welding which causes extremely rapid heating and cooling; to a 15 manufacturing method of the structural Fe-Cr steel sheet described above; and to a structural shaped steel manufactured therefrom.

2. Description of the Related Art

[0002] In addition to strength, corrosion resistance and durability have been required for civil engineering and architectural structures. Accordingly, as materials for use in the application 20 described above, primarily used are ordinary steel such as SS400 defined by JIS G 3101 (1995) and SN400B defined by JIS G 3136 (1994); high tensile steel such as SM490 defined by JIS G 3106 (1999); and materials formed of the steel described above processed, for example, by coating, plating, and cationic electrodeposition (electrophoretic deposition) coating. In addition, as materials used for general architectural structures, various shaped steel, such as welded 25 lightweight H-shaped steel defined by JIS G 3353 (1990) including SWH400, have been used.

In addition, in recent years, concomitant with diversification of design and increasing attention to environmental concern, studies on the use of various types of materials have been carried out.

[0003] Among the various types of materials, Fe-Cr steel, which has superior corrosion resistance and higher design performance, has drawn intensive attention as a very attractive

5 candidate in view of life cycle cost (LCC). The reason for this is that the maintenance cost of the steel described above for plating treatment, anti-rusting coating, touch-up treatment after punching or welding, and the like, which primarily relate to preventing rust generation, is not substantially required.

[0004] Among various types of Fe-Cr steel, described above, as a civil engineering and

10 architectural structural material, an austenitic stainless steel such as SUS304A defined by JIS G 4321 (2000) has been studied, which has been most widely used because of its material strength, corrosion resistance, easy weldability, toughness of welded portions, and easy availability. This austenitic stainless steel has sufficient characteristics used as a civil engineering and architectural material in view of the strength, corrosion resistance, fire resistance, toughness of

15 welded portions and the like. However, since the austenitic stainless steel contains a large amount of alloying elements such as nickel (Ni) and chromium (Cr), the price is considerably high as compared to that of ordinary steel. Hence, it has been difficult to substitute the stainless steel described above for conventional ordinary steel, high tensile steel, and materials formed of the steel mentioned above processed by plating or coating, and as a result, a problem has

20 occurred in that the application of the austenitic stainless steel has been extremely limited.

[0005] To solve the problem described above, improvement of martensitic stainless steel, such as SUS410 or SUS410S, defined by JIS G 4304 (1999), containing no expensive Ni and a relatively small amount of Cr, has been performed to develop a material for use in civil

engineering and architectural application. The martensitic stainless steel has advantages in that there is no concern about σ embrittlement, 475°C embrittlement, and the like, which are problems for a high Cr alloy, and that stress corrosion cracking, which is a problem for austenitic stainless steel, does not substantially occur under the conditions in which a chloride is present.

[0006] For example, martensitic stainless steel for welded structures, having improved characteristics of welded portions, has been disclosed in Japanese Examined Patent Publication No. 51-13463, in which the contents of Cr, Ni, silicon (Si), and manganese (Mn) are 10 to 18 wt%, 0.1 to 3.4 wt%, 1.0 wt% or less, and 4.0 wt% or less, respectively. Further, the contents of carbon (C) and nitrogen (N) are decreased to 0.03 wt% or less and 0.02 wt% or less, respectively; and a massive martensitic structure is generated in a welding heat-affected zone. In addition, structural martensitic stainless steel, having high toughness of a welded portion and superior workability, has been disclosed in Japanese Examined Patent Publication No. 57-28738, in which the contents of Cr, Si, and Mn are 10 to 13.5 wt%, 0.5 wt% or less, and 1.0 to 3.5 wt%, respectively; the contents of C and N are decreased to 0.02 wt% or less and 0.02 wt% or less, respectively; and the content of Ni is limited to less than 0.1 wt% so that preheating before and post heating after welding are not required.

[0007] In Japanese Unexamined Patent Publication No. 2002-53938, a technique has been disclosed for improving initial rust resistance, workability, and weldability of an alloy, in which cobalt (Co), vanadium (V), and tungsten (W) are particularly added in combination to a Fe-Cr alloy containing Cr in the range of more than 8 mass% to less than 15 mass%, and in addition, increase of Ni, copper (Cu), Cr, molybdenum (Mo), and the like, addition of titanium (Ti) and niobium (Nb), and excessive decrease of C and N are not performed. However, the steel

materials disclosed in Japanese Examined Patent Publication Nos. 51-13463 and 57-28738, have an excessively high as-hot rolled strength, annealing must be performed after hot rolling, and hence there have been problems with cost and smooth delivery. In addition, the technique disclosed in Japanese Unexamined Patent Publication No. 2002-53938, the addition of Co, V, 5 and W in combination must be performed. Also, annealing of the hot rolled sheet is recommended for softening.

[0008] Accordingly, development of cost-reduction techniques, for example, for decreasing the amount of an alloy element or by omitting an annealing step of a hot rolled sheet, has been implemented. For example, in Japanese Unexamined Patent Publication No. 11-302737, a 10 technique for omitting annealing of a hot rolled sheet has been disclosed, in which a steel raw material, containing 8 to 16 wt% of Cr, 0.05 to 1.5 wt% of Si, and 0.05 to 1.5 wt% of Mn, and containing C, N, and C + N at decreased contents of 0.005 to 0.1 wt%, 0.05 wt% or less, and 0.1 wt% or less, respectively, is heated to 1,100 to 1,250°C, and is then hot rolled. After hot rolling is finished at 800°C or more, coiling is performed at 700°C or more, and cooling is then 15 performed at an average cooling rate of 5°C/min or less. However, the steel material disclosed in Japanese Unexamined Patent Publication No. 11-302737 has a tensile strength of more than 450 MPa, and hence when the material described above is formed into shaped steel or pipes or is processed by secondary elaboration, drilling, and the like, it is difficult to used the production line designed for SS400, which has been processed, without any enhancement of the line.

20 [0009] In addition, although having superior arc weldability such as MIG using a welding rod, the steel material formed by the conventional technique described above does not have sufficient measures against hardening and embrittlement problems of welded portions which is rapidly heated and cooled, for example, by electric resistance welding. For example, a technique for

manufacturing structural welded lightweight H-shaped steel has been disclosed in Japanese Unexamined Patent Publication No. 2-305939, in which a steel material, containing 3.5 to less than 10.5 wt% of Cr, 0.01 to 1.0 wt% of Si, and 0.01 to 2.5 wt% of Mn, and containing C and N at decreased contents of 0.001 to 0.1 wt% and 0.001 to 0.10 wt%, respectively, is welded by

5 electric resistance welding in a non-oxidizing atmosphere or in a reducing flame shield. However, according to the technique described above, when welding is performed in the air, a so-called "penetrator", an oxide generated by heating during the welding, is not removed but that it remains, and as a result, a problem may arise in that breakage occurs at welded portions in a step of applying a tensile force. Accordingly, another problem may arise in that facilities for

10 controlling the atmosphere become necessary.

[0010] As described above, since many hot rolled Fe-Cr steel sheets formed by conventional techniques have an as-hot rolled tensile strength of more than 450 MPa, a problem may arise when production facilities, which have been used for manufacturing shaped steel using SS400, are used without any enhancement. In particular, the front and rear ends in the longitudinal direction and edge portions in the width direction of a hot rolled coil must be cut away since the strength thereof is largely increased, and as a result, the production yield is unfortunately decreased. In addition, since the steel sheets manufactured by conventional techniques do not have sufficient measures against hardening and embrittlement problems of welded portions which are rapidly heated and cooled by electric resistance welding or the like, a problem may

15 arise when the steel sheets described above are used as a raw material for forming welded lightweight H-shaped steel and electric resistance welded (ERW) tubes by electric resistance welding.

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[0011] In consideration of the problems described above, it would be advantageous to provide a structural Fe-Cr steel sheet and an inexpensive manufacturing method thereof, the Fe-Cr steel sheet having an as-hot rolled tensile strength, that is, a tensile strength of a hot rolled sheet obtained without annealing, of 400 to 450 MPa in the entire longitudinal and width directions of
5 a coil of the steel sheet, and generating no embrittlement in welded portions even when rapid heating and cooling are performed by electric resistance welding. In addition, it would be advantageous to provide structural shaped steel which is formed by electric resistance welding using the steel sheet described above.

10 SUMMARY OF THE INVENTION

[0012] Accordingly, a summary of the invention is as follows.

[0013] In accordance with one aspect of the invention, a structural Fe-Cr steel sheet comprises: about 0.0025 to about 0.010 mass% of C; about 0.0025 to about 0.010 mass% of N; about 0.015 mass% or less of C + N; about 0.01 to about 1.0 mass% of Si; about 0.01 to about 0.30 mass%
15 of Mn; about 0.04 mass% or less of phosphorous (P); about 0.03 mass% or less of sulfur (S); about 8 mass% to less than about 10 mass% of Cr; about 0.01 to about 1.0 mass% of Cu; about 0.01 to about 1.0 mass% of Ni; about 0.01 to about 0.20 mass% of V; about 0.05 mass% or less of aluminum (Al); and the balance being iron (Fe) and incidental impurities, wherein the tensile strength is about 400 to about 450 MPa.

20 [0014] The structural Fe-Cr steel sheet of the invention may further comprise about 1.0 mass% or less of Mo.

[0015] According to another aspect of the invention, a method for manufacturing a structural Fe-Cr steel sheet comprises: heating a steel raw material to a temperature of about 1,100 to

about 1,280°C, which comprises about 0.0025 to about 0.010 mass% of C; about 0.0025 to about 0.010 mass% of N; about 0.015 mass% or less of C + N; about 0.01 to about 1.0 mass% of Si; about 0.01 to about 0.30 mass% of Mn; about 0.04 mass% or less of P; about 0.03 mass% or less of S; about 8 mass% to less than about 10 mass% of Cr; about 0.01 to about 1.0 mass% of Cu; about 0.01 to about 1.0 mass% of Ni; about 0.01 to about 0.20 mass% of V; about 0.05 mass% or less of Al; and the balance being Fe and incidental impurities: hot rolling the steel raw material into a steel sheet; finishing the hot rolling at a temperature of more than about 930°C; coiling the steel sheet at a temperature of more than about 810°C to form a coil; and cooling the coil at an average cooling rate of about 2°C/min or less from about 800 to about 10 400°C, which is an average cooling rate of inside the coil, to obtain a tensile strength of about 400 to about 450 MPa.

[0016] In the manufacturing method described above, when higher corrosion resistance is required, the steel raw material may further comprise about 1.0 mass% or less of Mo.

[0017] In the manufacturing method of the invention, described above, hot rolling may comprise 15 rough rolling at least one pass with a reduction in thickness of about 30% or more at a temperature of more than about 1,000°C.

[0018] In the cooling the coil step of the manufacturing method of the invention, the average cooling rate of about 2°C/min or less from about 800 to about 400°C is preferably a cooling rate of every point of the entire coil, and in addition, the cooling the coil step is preferably performed 20 by using one of a heat insulating box, a heat insulating cover, and a heat insulating furnace.

[0019] According to another aspect of the invention, structural shaped steel is formed by electric resistance welding using the steel sheet described above or the steel sheet formed by the manufacturing method described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Fig. 1 is a graph showing an example of results obtained by calculating the temperature history of a hot rolled coil after coiling;

5 Fig. 2 is a graph showing an example of results obtained by calculating the temperature history of a hot rolled coil which is covered with a heat insulating cover after coiling;

Fig. 3 is an example of the heat insulating cover; and

Fig. 4 is a graph showing cooling curves shown in Fig. 2 and a curve of a cooling rate of 2°C/min together with CCT diagrams.

10 DETAILED DESCRIPTION

[0021] We focused on a low alloy steel containing Cr from about 8 mass% to less than about 10 mass% and carried out an intensive study of compositions of the steel, having an as-hot rolled strength of about 400 to about 450 MPa and superior electric resistance weldability, and the manufacturing method thereof to obtain a material having corrosion resistance necessary for

15 civil engineering and architectural structures and to realize cost reduction. As a result, it was found that in a steel sheet containing Cr from about 8 mass% to less than about 10 mass%, since a fine martensitic structure is formed in welding heat-affected zones, to prevent embrittlement of the welded portions, it is important to prevent the martensitic structure in the heat-affected zone from being excessively hardened.

20 [0022] The hardness of a martensite phase largely depends on the content of C and N dissolved in a steel material. Accordingly, by a conventional technique using a welding method such as arc welding in which a cooling rate after welding is relatively slow, the content of C and N in a steel sheet can be decreased, and in addition, by annealing a hot rolled steel sheet, a steel can be

obtained having a strength of 400 to 450 MPa, superior workability and weldability, and in addition, having excellent toughness of a welded portion. However, when electric resistance welding, which has been used for manufacturing welded lightweight H-shaped steel or an electric resistance welded tube, is applied to a conventional steel sheet, hardening in a heat-
5 affected zone considerably occurs, a problem may arise in that sufficient balance between strength and toughness cannot be obtained. In particular, the embrittlement described above occurs most considerably in a portion heated to 800 to 900°C in welding.

[0023] The reasons for this have been believed as described below. A conventional structural steel in a temperature range of from 800 to 900°C has a two-phase structure of ferrite phase(α)+
10 austenite phase(γ). However, the contents of C and N dissolved in the α and γ phases are very different from each other. In portions made of the γ phase, the contents of C and N are increased as compared to those in a single γ phase. The γ phase containing such concentrated C and N is transformed to a hard martensite phase during cooling after welding, and as a result, embrittlement occurs in welded portions. However, by general arc welding, since the vicinity of
15 the welded portion is air-cooled (spontaneously cooled) after welding, hardening of the martensite phase described above does not occur much. On the other hand, by electric resistance welding, rapid heating and cooling considerably occur concomitant with welding, and in addition, when the vicinity of welding portions is water-cooled to prevent overheating of peripheral devices such as a welding tip, since a steel sheet in the vicinity of welding portions is
20 very rapidly cooled immediately after welding to form a hard martensite phase, embrittlement considerably occurs. Accordingly, the control of composition and microstructure of the steel material becomes increasingly important for a steel material processed by electric resistance welding.

[0024] To solve the problem of embrittlement of welded portions, we first tried to decrease the contents of C and N. However, an excessive decrease in C and N did not only cause a decrease in martensite production ability of the welding heat-affected zone, but also produced so-called "coarse" and "large" ferritic grains, and as a result, the characteristics of the welded portion 5 were degraded. In addition, in the case in which a strong element, such as Ti or Nb, forming a carbonitride was added, the contents of the dissolved C and N were also excessively decreased, and as a result, the same result was unfortunately obtained.

[0025] Accordingly, to improve the electric resistance welding properties, we considered that it is necessary to improve the microstructure of a ferrite phase + martensite phase, which is 10 generated by heating to the two-phase temperature region of $\alpha+\gamma$ in welding followed by cooling. Hence, we carried out a further intensive study focusing on two aspects, that is, improvement in toughness of the ferrite phase by forming finer ferritic crystal grains of a parent material in addition to prevention of hardening of the martensite phase. As a result, we discovered that by adding an appropriate amount of V, in addition to decreasing the contents of C and N, the 15 increase in hardness of the martensite phase generated at the two-phase temperature region can be suppressed. In addition, by performing rough rolling at least one pass with a reduction in thickness of about 30% or more in hot rolling, we also discovered that a finer ferrite structure, which is the parent material, can be obtained and that, as a result, embrittlement which occurs at the two-phase temperature region by electric resistance welding can be significantly improved. 20 In addition, among the components of the steel, in particular, in addition to decreased Cr and Mn, when an appropriate amount of Cu is added, we discovered that generation of a penetrator remaining in the welded portion can be suppressed and that even in air, electrical resistance welding can be advantageously performed.

[0026] Further, we carried out an intensive study of a method for obtaining a coil having an as-hot rolled strength of 400 to 450 MPa in the entire longitudinal and width directions thereof. First, in order to accurately grasp the cooling rate of the coil, a thermocouple was actually fixed to a coil which was hot rolled, and the temperature thereof was measured with time. Based on 5 the results, the cooling rate at each position of the coil was calculated. The calculation was performed assuming that the coil weight was 12,300 kg, the coil width was 1,450 mm, the inside diameter was 760 mm, the coiling temperature was 850°C, and the outdoor air temperature was 20°C.

[0027] One example of the results is shown in Fig. 1. As can be seen from Fig. 1, at a coldest 10 point T_{min} (an edge portion in the width direction of the outermost portion of the coil, hereinafter referred to as a “coil coldest point”), the temperature was decreased to approximately 400°C for just approximately 30 minutes, and it was understood that cooling was performed at a high speed of approximately 13°C/min between 800 to 400°C. As a result, it is believed that at the front and rear ends in the longitudinal direction (inner portion and outer portion) of the coil 15 and the edge portions in the width direction thereof, many hard phases, such as a martensite phase and a bainite phase, are formed and are further hardened.

[0028] Accordingly, we collected metallurgical data, such as continuous cooling transformation diagrams (CCT diagram), isothermal time-temperature-transformation diagrams (TTT diagram), and the like, of an alloy containing Cr in the range of from 8 mass% to less than 10 mass%, and 20 the transformation behavior was investigated when heat insulation was performed during the cooling. To prevent the front and the rear end portions in the longitudinal direction of the coil and the edge portions in the width direction thereof from being hardened, heat insulation is started by using a certain type of means after coiling is completed and before the portions

described above are cooled to less than about 400°C so that the average cooling rate from about 800 to 400°C is controlled to be 2°C/min or less by a recuperation effect of increasing temperature using the heat inside the coil and an effect of slow cooling obtained by suppressing heat dissipation using the heat insulation.

- 5 [0029] As a result, it was found that desired softening can be achieved in the entire longitudinal and width directions of an as-hot rolled coil. In the invention, the average cooling rate does not mean that an average cooling rate of about 2°C/min or less must be controlled at every moment from about 800 to about 400°C, but it means that the time for cooling from about 800 to about 400°C is controlled to be about 200 minutes or more so that an average cooling rate of about
10 2°C/min or less is obtained.

- [0030] Fig. 2 shows an example of results obtained by calculating the coil temperature with time in the case in which, as shown in Fig. 3, a coil was covered with a heat insulating cover after 30 minutes from the completion of the coiling, wherein the heat insulating cover was lined with an insulating material 100 mm thick and was used as one heat insulating means. From Fig. 2, it is
15 understood that by using the heat insulating cover, since even the coldest point T_{min} of the coil was cooled from about 800 to about 400°C for about 400 minutes or more, cooling can be performed at an average cooling rate of about 1°C/min or less.

- [0031] In addition, in Fig. 4, the cooling curves shown in Fig. 2, a curve showing a cooling rate of 2°C/min, and CCT diagrams are shown all together. Marks F, B, and M in Fig. 4 indicate
20 generation regions of a ferrite phase, a bainite phase, and a martensite phase, respectively. In the case in which the cooling is continuously performed at a constant cooling rate, when the cooling rate from about 800 to about 400°C is set to about 2°C/min or less, that is, when the cooling from about 800 to about 400°C is performed for about 12,000 seconds (about 200

minutes) or more, it is understood that a soft single ferrite phase structure can be obtained with no generation of a bainite phase. In addition, when the heat insulation is performed, an optional position of the coil is processed by the temperature history represented by the region surrounded by Tmax and Tmin. However, when the heat insulation is performed before the temperature, 5 even at the coldest point shown by the line of Tmin, is decreased to less than about 400°C, it is understood that the generation of a hard martensite phase can be substantially suppressed. Furthermore, it is also understood that a bainite phase generated in a part of the coil by cooling performed before the heat insulation can be transformed to tempered bainite or a ferrite phase by tempering because of the recuperation effect after the heat insulation, and that as a result, 10 softening can be achieved. Accordingly, when the insulating cover is used, by the manufacturing method of the invention, a Fe-Cr steel sheet for use in architectural structure applications can be provided at a reasonable price.

[0032] Hereinafter, selected embodiments of the invention will be described in detail.

[0033] First, the reason the composition of the steel sheet of the invention is limited will be 15 described.

C: about 0.0025 to about 0.010 mass%, N: about 0.0025 to about 0.010 mass%, and C + N: about 0.015 mass% or less

[0034] The welding heat-affected zone of the steel according to the invention forms a fine 20 martensitic structure. The contents of C and N have a large influence on the hardness of the martensite phase generated in the welding heat-affected zone. It is effective to decrease the contents of C and N to improve the toughness and the workability of the welding heat-affected zone so as to prevent weld cracking, as has been known. However, in addition to the increase in refining cost, excessive decrease in C and N decreases the martensite production ability of the 25 welding heat-affected zone, facilitates the generation of coarse and large ferritic grains, and as a

result, considerably decreases the toughness of welded portions. Hence, the contents of C and N are each set to about 0.0025 mass% or more. On the other hand, the upper limits of the contents of C, N, and C + N are set to about 0.010 mass%, about 0.010 mass%, and about 0.015 mass%, respectively to prevent extreme increase in hardness of the martensite phase generated in the welding heat-affected zone and to prevent the embrittlement thereof. Preferable ranges of the contents of C and N are about 0.003 to about 0.008 mass% and about 0.0030 to about 0.0060 mass%, respectively. In particular, when electric resistance welding is performed in air, the content of N is preferably set to about 0.006 mass% or less. In addition, the content of C is more preferably in the range of from about 0.003 to about 0.005 mass%.

10 Si: about 0.01 to about 1.0 mass%

[0035] Si is an element added to be used as a deoxidizing agent and also to increase strength. Sufficient deoxidizing effect cannot be obtained when the content is less than about 0.01 mass%. On the other hand, when the content is excessively high such as about 1.0 mass% or more, in addition to the decrease in toughness and workability, the martensite production ability of the welding heat-affected zone is decreased. Accordingly, the content of Si is set to the range of from about 0.01 to about 1.0 mass%. The content is particularly preferable in the range of from about 0.1 to about 0.5 mass%.

Mn: about 0.01 to about 0.30 mass%

[0036] Mn is an element stabilizing an austenite phase (γ phase) and allowing the welding heat-affected zone to have a martensitic structure, thereby contributing to improvement in toughness of the welded portion. However, when the content is excessively high, the ratio of an as-hot rolled hard phase is increased, and as a result, the targeted tensile strength (about 400 to about 450 MPa) cannot be obtained. In addition, the hardness of the martensite generated at the two-

phase temperature region by electric resistance welding is increased to cause the embrittlement thereof. Further, MnS is formed to decrease the corrosion resistance. Accordingly, the upper limit of the Mn content is set to about 0.30 mass%. On the other hand, the lower limit of the Mn content is set to about 0.01 mass% since Mn is an effective deoxidizing agent as is Si. A 5 particularly preferable range is about 0.10 to about 0.30 mass%.

P: about 0.04 mass% or less

[0037] P is a hazardous element which does not only decrease hot-workability, formability, and toughness, but also degrades corrosion resistance. In particular, when the content of P is more than about 0.04 mass%, since the influence thereof becomes significant, the content is limited to 10 about 0.04 mass% or less. A more preferable content is about 0.030 mass% or less.

S: about 0.03 mass% or less

[0038] S reacts with Mn to form MnS, thereby causing a decrease in corrosion resistance and durability. In addition, S is a hazardous element which exists locally in crystal grain boundaries to facilitate grain boundary embrittlement, and hence the content of S is preferably decreased as 15 much as possible. In particular, when the content is more than 0.03 mass%, the adverse influence becomes significant, and hence the content is limited to about 0.03 mass% or less. A more preferable content is about 0.008 mass% or less.

Cr: about 8 mass% to less than about 10 mass%

[0039] Cr is an effective element for improving corrosion resistance. However, when the 20 content is less than about 8 mass%, sufficient corrosion resistance cannot be reliably obtained. On the other hand, when the content of Cr is increased to about 10 mass% or more, the cost is inevitably increased, and in addition, it becomes difficult to obtain the desired as-hot rolled

strength. Hence, the content is limited to the range of from about 8 mass% to less than about 10 mass%.

Cu: about 0.01 to about 1.0 mass%

[0040] Cu is an effective element for improving corrosion resistance and is added for improving
5 the life of architectural structures and the like. In addition, in particular, Cu is an element which
is positively used to perform electric resistance welding in air. The reason the remaining
penetrator, which is generated in welding, can be reduced by the addition of Cu has not been
clearly understood. However, we believed that, in addition to the decrease in amount of an
element, such as Cr or Mn, which is likely to form an oxide in the welded portion, when an
10 appropriate amount of Cu, which is a noble element (being unlikely to be ionized as compared
to iron, or having a higher standard electrode potential than that of iron), is added, generation of
an oxide in the welded portion can be suppressed. However, when the addition is less than
about 0.01 mass%, the effect described above cannot be satisfactorily obtained, and on the other
hand, when the content of Cu is excessively high such as more than about 1.0 mass%, in
15 addition to the increase in cost, hot-cracking sensitivity is enhanced. Hence the embrittlement
may occur during hot rolling in some cases. Accordingly, the addition is limited to the range of
from about 0.01 to about 1.0 mass%. The lower limit of Cu is preferably set to about 0.1 mass%
at which an apparent effect of improving the corrosion resistance can be obtained, and on the
other hand, the upper limit is preferably set to about 0.7 mass% to prevent hot cracking and to
20 obtain good workability.

Ni: about 0.01 to about 1.0 mass%

[0041] Ni is an element which improves ductility and toughness. Ni is used to improve the
toughness of the welding heat-affected zone and, in addition, to improve anti-rusting properties.

In addition, hot cracking which occurs during hot rolling when Cu is added can be effectively prevented by addition of Ni. However, when the content of Ni is less than about 0.01 mass%, the effect described above is not so significant, and on the other hand, when the content of Ni is more than about 1.0 mass%, the effect described above is saturated, and the material is hardened or the cost is increased. Accordingly, the amount of Ni is limited to the range of from about 5 0.01 to about 1.0 mass%.

V: about 0.01 to about 0.20 mass%

[0042] V is a very important element, and by addition of an appropriate amount thereof, embrittlement of the welding heat-affected zone, caused by electric resistance welding, can be prevented. In addition, formation of coarse and large ferritic crystal grains can also be prevented. 10 However, the effect described above is not so significant when the content is less than about 0.01 mass%. On the other hand, when the content is more than 0.20 mass%, the martensite production ability of the welding heat-affected zone is considerably decreased, the toughness of the welded portion is decreased, and in addition, it becomes difficult to obtain a desired as-hot 15 rolled tensile strength (about 400 to about 450 MPa). Accordingly, the content of V is limited to the range of from about 0.01 to about 0.20 mass%. A preferred amount is about 0.03 to about 0.20 mass%.

[0043] Although the mechanism in which embrittlement of the welding heat-affected zone is suppressed by the addition of V has not been clearly understood, it has been considered as 20 follows. When an element such as Ti or Nb, having a strong affinity for C and N, is added, since the carbonitride thereof is formed and precipitated, the amounts of dissolved C and N are considerably decreased, and as a result, the martensite production ability of the welding heat-affected zone is significantly decreased. On the other hand, when V is added, since the affinity

thereof for C and N is not so strong as compared to that of Ti or Nb, in a portion heated to a γ single-phase temperature region or more, a significant decrease in the amount of dissolved C and N does not occur, and hence the martensite production ability of this portion can be sufficiently ensured. On the other hand, in a portion heated to the two-phase temperature region, since the 5 carbonitride of V in this temperature region is stable, and the amounts of dissolved C and N are decreased to a low level, hardening of the martensite phase caused by increase in concentration of dissolved C and N in the γ phase is unlikely to occur. As a result, without decreasing the martensite production ability of the portion heated to the γ single-phase temperature region or more, the hardness of the martensite phase formed at the two-phase temperature region can be 10 decreased to a lower level, and as a result, over the entire region of the welding heat-affected zone, a superior toughness can be obtained.

Al: about 0.05 mass% or less

[0044] Al is not only effective as a deoxidizing agent but also can contribute to improvement in bending workability of a steel sheet. To obtain the effect described above, the amount of about 15 0.003 mass% or more must be added. However, when the amount is increased to more than about 0.05 mass%, inclusion particles are increased, and as a result, the mechanical characteristics are degraded thereby. Accordingly, the amount of Al is limited to about 0.05 mass% or less. In addition, in particular, Al may not be contained/included at all.

Mo: about 1.0 mass% or less

20 [0045] Mo is also an effective element which can improve corrosion resistance. It may be added whenever desired. The amount of about 0.03 mass% or more is added to obtain the effect described above. However, when the amount is increased to more than about 1.0 mass%, workability is considerably degraded, and in addition, a desired as-hot rolled tensile strength

(about 400 to about 450 MPa) cannot be obtained. Accordingly, the amount of Mo is limited to about 1.0 mass% or less. In addition, in view of the balance among corrosion resistance, strength, and workability, the amount is preferably in the range of from about 0.1 to about 0.5 mass%.

5 [0046] Next, the characteristics of the steel sheet of the invention will be described.

[0047] The steel sheet of the invention must have a tensile strength in the range of from about 400 to about 450 MPa. Heretofore, shaped steel used for civil engineering and architectural structures has been manufactured by primarily processing SS400 steel, and to utilize the same production line as that for SS400, the steel must have strength and workability equivalent to 10 those of SS400. That is, when the tensile strength is more than about 450 MPa, it is not preferable since work load applied to the production line of the shaped steel is increased, the facilities must be enhanced thereby, and in addition, the workability is also degraded. On the other hand, when the strength is less than about 400 MPa, an excessive deformation may occur when the shaped sheet is fabricated, and in addition, the strength necessary used as a finished 15 product may not be obtained in some cases.

[0048] Next, a method for manufacturing a Fe-Cr steel, according to the invention will be described.

[0049] After molten steel having the composition according to the invention is formed by a generally known melting furnace such as a converter or an electric furnace, refining is performed 20 by a known refining method, such as a vacuum degassing (RH) method, a vacuum oxygen decarburization (VOD) method, an argon oxygen decarburization (AOD) method, or the like, and next, by a continuous casting method or a ingot making method, a steel slab (steel raw

material) is formed. In this case, the thickness of the slab is preferably about 100 mm or more to reliably ensure the reduction in thickness in hot rough rolling described later.

[0050] Next, after the steel slab is heated to a temperature of about 1,100 to about 1,280°C, hot rolling is performed, thereby forming a hot rolled steel sheet. The slab heating temperature is 5 preferably high from the viewpoint that softening is facilitated by self-annealing after the completion of coiling. However, when it is more than about 1,280°C, slab sagging considerably may occur in some cases, coarse and larger crystal grains are formed, and as a result, the toughness of the hot rolled sheet is decreased. On the other hand, when the heating temperature is less than about 1,100°C, it becomes difficult to perform hot rolling at a finishing temperature 10 of more than about 930°C. Hence, the heating temperature is preferably in the range of from about 1,100 to about 1,250°C.

[0051] In a step of hot rough rolling of the invention, rolling with a reduction in thickness of about 30% or more is preferably performed at least one pass in a temperature range of more than about 1,000°C. The reason for this is that by this rolling with a high reduction in thickness, the 15 crystal structure of the steel sheet becomes finer to suppress the decrease in toughness of the parent material. The decrease in toughness of the parent material, described above, is caused by formation of coarse and large ferritic crystal grains, which primarily occurs in the central portion in the longitudinal direction of the coil when the cooling rate is decreased by heat insulation after the completion of coiling. (Heat insulation will be described later.)

20 [0052] In addition, the hot rough rolling with a high reduction in thickness also has an effect of improving the toughness of a portion heated by electric resistance welding to the two-phase temperature region of a ferrite phase (α) and an austenite phase (γ). The reason for this is that the martensite at the two-phase temperature region is generated in ferritic crystal boundaries of

the steel sheet, and when this is excessively hardened, sites generating cracks are formed, and embrittlement occurs. Accordingly, when the ferritic structure as a matrix is made to have a finer structure to improve the toughness thereof, propagation of cracks can be prevented, and hence embrittlement can be suppressed.

- 5 [0053] The reason for this is that although the steel sheet is an austenite (γ) single phase at a temperature of more than 1,000°C, when the reduction in thickness per pass is set to about 30% or more, the number of sites generating the ferrite phase is increased, and hence the finer crystal grains can be obtained. In addition, the reason the rolling temperature is set to more than about 1,000°C in this case is that the finish temperature of hot rolling is also set to more than about
10 930°C.

- [0054] A final temperature in finish rolling following the hot rough rolling is set to more than about 930°C, and the coiling temperature after the rolling is set to more than about 810°C to facilitate the softening by a self-annealing effect obtained after the completion of coiling. The reason the final temperature of the finish rolling is set to more than 930°C is to prevent the
15 formation of a deformed ferrite phase by rolling in the two-phase temperature region of a ferrite phase (α) and an austenite phase (γ) and to ensure a coiling temperature of more than about 810°C. In addition, the reason the coiling temperature is set to more than about 810°C is that by maintaining the high temperature inside the coil, the recuperation effect can be easily obtained when heat insulation is performed after completion of coiling. In addition, the coiling
20 temperature must be set to more than about 810°C to obtain a temperature of 400°C or more at the edge portions in the width direction of the coil when the heat insulation is started.

[0055] In addition, to obtain the targeted strength, the cooling time for the coil from about 800 to about 400°C must be set to about 200 minutes or more after the completion of the coiling so

that the cooling is performed at an average cooling rate of about 2°C/min or less. By the average cooling rate described above, the steel sheet structure can be formed of a ferrite single phase (partly including a carbonitride), a tempered bainite single phase, or a tempered bainitic + ferritic structure, and as a result, the growth of a hard martensite phase can be perfectly prevented.

- [0056] In this embodiment, the average cooling rate inside the coil is a cooling rate measured inside the coil, that is, measured at a position in the vicinity of the center in the longitudinal direction of the coil and at a distance of about 50 mm or more from the edge in the sheet width direction. The measurement may be performed by inserting a thermocouple into the coil.
- 10 Alternatively, the rate may be estimated by using an equation based on the surface temperature of the coil.

[0057] In the case described above, inside the coil described above, the steel sheet after the completion of coiling can be relatively easily cooled at an average cooling rate of about 2°C/min or less. However, at the front end portion (inner portion) the rear end portion (outer portion) in 15 the longitudinal of the coil, and the end portions (edge portions) of the coil in the width direction, the average cooling rate is likely to be more than about 2°C/min, and as a result, a bainite phase or a martensite phase is easily generated to form a hard structure. Accordingly, the portions described above must be cut away, thereby causing the problem of a decrease in production yield.

- 20 [0058] To solve the problem described above, the invention provides a method in which heat insulation is started before the temperature of the coil after the completion of coiling is decreased to less than about 400°C, and in which by using the recuperation effect obtained by this heat insulation, the cooling time from about 800 to about 400°C, which is a temperature

- substantially at every position of the coil, is set to about 200 minutes or more so as to obtain an average cooling rate of about $2^{\circ}\text{C}/\text{min}$ or less. By the heat insulation described above, the end portions in the longitudinal and width direction of the coil can be sufficiently annealed, and as a result, the coil can obtain the targeted strength in the entire width and longitudinal directions
- 5 thereof. The average cooling rate is more preferably set to about $1^{\circ}\text{C}/\text{min}$ or less. In this case, since the coldest point of the coil corresponds to each of the two end portions in the width direction of the outermost portion of the coil, when a thermocouple is welded to this position, the cooling rate can be measured. In addition, temperature measurement may be performed by a radiation thermometer.
- 10 [0059] As a heat insulating method, for example, there may be mentioned a method in which the coil is covered with a heat insulating cover made of iron and lined with a heat insulating material inside thereof; a method in which the coil is placed in a heat insulating box formed by digging a pit and adhering a heat insulating material to the walls thereof and, if necessary, the coil is covered with a heat insulating cover; or a method using a device provided with a heating
- 15 function, and in consideration of individual production facilities, heat insulating devices suitable thereto may be selectively used. In addition, in consideration of cooling performed from the lower side of the coil, possible measures, for example, in which the coil is placed on a heat insulating material, must be taken whenever necessary. In addition, in particular, to the front and the rear end portions in the longitudinal direction of the coil and the two end portions in the
- 20 width direction thereof, which are very rapidly cooled after the completion of coiling, induction heating or the like may be additionally used.
- [0060] By using the heat insulating method described above, without performing annealing of a hot rolled steel sheet, a steel sheet can be obtained having an as-hot rolled tensile strength of

about 400 to about 450 MPa in the entire longitudinal and width directions of the coil, and hence the problem of the conventional technique in which the front and the rear ends in the longitudinal direction of the coil must be cut away and/or the edge portions in the width direction of thereof must be largely trimmed can be suppressed. Hence the decrease in 5 production yield can be suppressed. Accordingly, significant cost reduction can be obtained. In addition, since the tensile strength is made equivalent to that of SS400 steel, machining such as bending and drilling can be performed in the same production line as that used for SS400.

[0061] In addition to superior workability and toughness in an as-hot rolled state, the hot rolled steel sheet of the invention also has superior characteristics in which embrittlement of the 10 welding heat-affected zone does not occur even by using electric resistance welding which causes rapid heating and cooling in welding. The steel sheet of the invention, which is in an as-hot rolled state, can be used, and in addition, it can also be used after being processed by skinpass rolling for shape compensation, whenever necessary; shotblasting, pickling, or the like for removing scale; or polishing for obtaining a desired surface condition. Furthermore, 15 whenever necessary, the steel sheet can be used after being processed by application of an anti-rusting agent or the like. When pickling is performed, to improve the pickling performance, annealing may be performed for the hot rolled steel sheet.

[0062] The steel sheet of the invention can be applied to various types of shaped steel, which are formed by bending machining, roll forming, and the like, and are suitably used for shaped steel 20 for civil engineering and architectural structures, and in particular, for housing structures. In addition, the steel sheet of the invention can be used as a material for shaped steel formed by various welding techniques such as arc welding, and in particular, since embrittlement of the welded portion caused by rapid heating and cooling does not occur at all, the invention is

preferably applied to manufacturing of welded lightweight H-shaped steel, electric resistance welded (ERW) tubes, square pipes, and the like formed by electric resistance welding using induction heating or direct electric heating.

[0063] Furthermore, the steel sheet of the invention may also be used as a material for various structures such as containers, coal wagons, and bus frames by effectively using the characteristics thereof. In addition, the steel sheet having the composition of the invention may also be applied to various steel materials, such as thick steel sheets formed by hot rolling, shaped steel, and steel bars, for use in civil engineering and architectural fields.

Examples

10 Example 1

[0064] Steel having the composition shown in Table 1 was formed into steel slabs 200 mm thick by melting through a converter-secondary refining step followed by continuous casting. After being reheated to 1,170°C, these steel slabs were processed by rough rolling with seven passes under the conditions shown in Table 2 in which the reduction in thickness at the sixth pass was set to 20 to 45% and those of the other passes were each set to less than 30%, were then processed by finish rolling with seven passes at a finish rolling temperature of 940 to 1,050°C to form hot rolled steel sheets 4.5 mm and 6.0 mm thick, and were coiled at a temperature of 815 to 910°C to form coils, followed by air cooling. In addition, by adjusting the coil weight of some coils, the cooling rate was changed. For example, by forming coils from a small lot so as to decrease the weight of each coil, the cooling rate can be increased. The coils formed by coiling were each provided with a thermocouple on the side of the coil that is measured at a position in the vicinity of the center in the longitudinal direction of the coil and at a distance of 50 mm or more from the edge in the sheet width direction to measure the cooling rate.

[0065] After the hot rolled steel sheet was cooled and then processed by shotblasting and pickling for scale removal, tensile test pieces (JIS NO. 5) were obtained therefrom along the rolling direction and in the vicinity of the position at which the temperature was measured, and the 0.2% proof stress, tensile strength, yield ratio, and elongation were measured. After this coil
5 was slit, welded H-shaped steel was formed therefrom by electric resistance welding, the H-shaped steel having a web height of 300 mm, a flange width of 150 mm, a web thickness of 4.5 mm, and a flange thickness of 6.0 mm. In manufacturing the H-shaped steel, a web material was sequentially brought into contact with the central portions in the width direction of two flange materials, followed by electric resistance welding. Welding was performed under the
10 conditions in which the atmosphere was air or purged with a nitrogen gas, the electrical power was 330 to 370 kW, and the welding speed was 20 to 40 m/min. From this welded H-shaped steel, H-shaped welded tensile test pieces, having a width of 35 mm along the welding direction, in accordance with JIS G 3353 were obtained by cutting, and each test piece was held at the two flange portions and was then pulled, thereby measuring the tensile strength and the breaking
15 position. In this test, it is necessary that the H-shaped steel be broken not at the welded portion, but at the web portion and have a desired strength.

[0066] The results are shown in Table 2. According to the steel sheet of the invention, the strength was equivalent to that of SS400 or SN400B, the strength of the H-shaped steel formed of the steel sheet described above was also equivalent to that of SWH400, embrittlement of the
20 welded portion caused by electric resistance welding did not occur at all, and every breakage occurred at the web portion. In addition, by welding performed even in air, superior welding could be performed, and breakage of the welded portion caused by a remaining penetrator did not occur at all. On the other hand, according to comparative examples, which were out of the

scope of the invention, the targeted strength (400 to 450 MPa) could not be obtained, and in the tensile characteristic test, breakage occurred at the welded portion, and in addition, a sufficient strength could not be obtained.

[0067] In particular, sample No. 10 had a steel sheet strength within the desired range. However, 5 since rough rolling with a high reduction in thickness was not performed, embrittlement of the welded portion formed by electric resistance welding considerably occurred, breakage occurred at the welded portion of the H-shaped steel in the tensile characteristic test, and the desired strength thereof could not be obtained. Sample No. 11 was cooled at a high cooling rate after hot rolling, and as a result, the desired strength could not be obtained. Since sample No. 14 and 10 sample No. 15 had an excessive C content and an excessive C + N content, respectively, embrittlement of the welded portion formed by electric resistance welding at the two-phase temperature region considerably occurred, and as a result, after formation of the H-shaped steel, the desired strength thereof could not be obtained. Sample No. 16 contained a small amount of Cu, and due to the influence of a remaining penetrator, in the tensile characteristic test of the H- 15 shaped steel, breakage occurred at the welded portion. Since sample No. 17 contained a small amount of V, embrittlement of the welded portion formed by electric resistance welding occurred concomitant with the formation of coarse and large ferritic crystal grains, and breakage occurred at the welded potion. Since sample No. 18 contained a large amount of Mn, hardening occurred in the heat-affected zone by electric resistance welding, and in the tensile characteristic 20 test of the H-shaped steel, breakage occurred at the welded portion.

Example 2

[0068] Steel having the composition shown in Table 3 was formed into steel slabs 200 mm thick by melting through a converter-secondary refining step followed by continuous casting. After

being reheated to 1,170 to 1,220°C, these steel slabs were processed by rough rolling with seven passes under the conditions shown in Table 4 in which the reduction in thickness at the sixth pass was set to 30 to 45% and those of the other passes were each set to less than 30%, were then processed by finish rolling with seven passes at a finish rolling temperature of 940 to

5 1,050°C to form hot rolled steel sheets 4.5 mm and 6.0 mm thick, and were coiled at a temperature of 815 to 910°C to form coils. The coils thus formed were conveyed to a heat insulating yard, the inside of which was covered with a heat insulating material, and were each covered with a heat insulating cover, the inside of which was lined with a heat insulating material 100 mm thick, whereby heat insulation was performed. The measurement of the

10 cooling rate of the coil was performed by a thermocouple welded to the vicinity of the edge of the outermost side of the coil. In addition, by adjusting the coil weight of some coils or by changing the thickness of the insulating material, the cooling rate was changed. From the edge portion in the width direction of the outermost portion of the hot rolled coil and from the 1/4 portion in the width direction thereof, test pieces in accordance with JIS NO. 5 were obtained by

15 cutting, and the tensile characteristic test was performed. The tensile direction was in the rolling direction.

[0069] The results are shown in Table 4. According to the steel sheet of the invention processed by slow cooling using the heat insulating cover, the strength was equivalent to that of SS400 or SN400B, hardening in the vicinity of the edge portion of the outermost portion of the coil,

20 which was the coldest point, did not substantially occur, and the targeted strength (400 to 450 MPa) could be obtained. On the other hand, according to comparative examples, which were out of the scope of the invention, the strength in the vicinity of the edge portion was particularly increased, and in comparative examples in which the composition was out of the scope of the

invention, the targeted strength could not be obtained even at the 1/4 width portion inside from the edge of the coil in the width direction. In particular, since sample No. 30 was cooled at a high cooling rate after the completion of coiling, the desired strength could not be obtained at the edge portion. In sample No. 31, the desired strength could not be obtained at both the edge
5 portion in the width direction and the 1/4 width portion for the same reason as described above. In addition, since the content of C of sample No. 34, the content of N of sample No. 35, and the content of C + N of sample No. 36 were out of the range of the invention, the desired strength could not be obtained. Furthermore, since the content of Cu of sample No. 37, the content of V of sample No. 38, and the content of Mn of sample No. 39 were out of the range of the invention,
10 the desired strength could not be obtained.

[0070] As has thus been described, according to the invention, by appropriately combining the composition of the steel sheet, the hot rolling conditions, and the cooling conditions after hot rolling, a structural Fe-Cr steel sheet can be obtained which has an as-hot rolled strength equivalent to the strength of SS400 and which does not cause hardening at the front and the rear
15 end portions in the longitudinal direction of the coil and at the edge portions in the sheet width direction thereof, and as a result, in the conventional production line, various shaped steel can be manufactured using the steel sheet described above. In addition, since the steel sheet of the invention can be fabricated by a welding method in which rapid heating and cooling are performed, structural shaped steel can be manufactured by electric resistance welding.
20 Furthermore, the steel sheet of the invention has sufficient corrosion resistance and durability used for civil engineering and architectural structures, the reduction in life cycle cost can be achieved, and hence the industrial and commercial values are very significant.

Table 1

Steel mark	Components (mass%)										Remarks		
	C	Si	Mn	P	S	Al	Cr	N	Cu	Ni	V	Mo	C+N
A	0.0060	0.22	0.24	0.030	0.003	0.009	9.42	0.0046	0.51	0.20	0.08	-	0.0106 Example
B	0.0025	0.20	0.27	0.025	0.006	0.010	9.96	0.0060	0.40	0.30	0.06	-	0.0085 Example
C	0.0100	0.20	0.05	0.027	0.009	0.008	8.04	0.0026	0.46	0.18	0.03	-	0.0126 Example
D	0.0054	0.21	0.30	0.026	0.004	0.020	9.44	0.0042	0.70	0.21	0.05	-	0.0096 Example
E	0.0060	0.30	0.27	0.030	0.002	0.009	9.06	0.0044	0.30	0.13	0.20	-	0.0104 Example
F	0.0060	0.10	0.26	0.010	0.001	0.001	8.97	0.0039	0.45	0.20	0.09	-	0.0099 Example
G	0.0065	0.22	0.24	0.015	0.003	0.009	8.80	0.0035	0.41	0.21	0.08	-	0.0100 Example
H	0.0094	0.46	0.15	0.030	0.003	0.010	9.42	0.0055	0.30	0.03	0.12	-	0.0149 Example
I	0.0051	0.22	0.26	0.030	0.003	0.011	9.10	0.0044	0.05	0.20	0.04	0.33	0.0095 Example
J	0.0055	0.20	0.25	0.029	0.005	0.014	9.23	0.0040	0.30	0.19	0.05	0.08	0.0095 Example
K	<u>0.0110</u>	0.21	0.25	0.035	0.006	0.010	8.89	0.0039	0.34	0.22	0.04	-	0.0149 Comparative example
L	0.0095	0.30	0.15	0.031	0.007	0.011	9.33	0.0058	0.30	0.01	0.04	-	<u>0.0153</u> Comparative example
M	0.0089	0.20	0.24	0.030	0.004	0.013	9.27	0.0044	<u><0.01</u>	0.21	0.08	-	0.0133 Comparative example
N	0.0092	0.25	0.25	0.029	0.003	0.012	9.29	0.0055	0.40	0.30	<u><0.01</u>	-	0.0147 Comparative example
O	0.0069	0.24	0.50	0.030	0.003	0.014	8.95	0.0060	0.31	0.20	0.08	-	0.0129 Comparative example

Note: Column with underline is out of the scope of the present invention

Table 2

No.	Steel mark	Hot-rolling conditions			Steel sheet characteristics (4.5 mm thick, L direction, JIS No. 5)			Manufacturing conditions for H-shaped steel			Tensile characteristics of H-shaped steel		Remarks	
		Roughing reduction in thickness at 6th pass (%)	Finish rolling temperature (°C)	Coiling temperature (°C)	Average cooling rate from 800 to 400°C (°C/min)	0.2% proof stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	Elongation (%)	Welding electrical power (kW)	Welding speed (mm/min)	Atmosphere	Breaking position	
1	A	35	980	830	0.6	252	410	61	40	340	30	Air	420	Web
2	A	35	1000	850	0.6	260	410	63	41	370	35	Purged with nitrogen	410	Web
3	B	30	980	820	2.0	245	402	61	42	360	35	Air	404	Web
4	C	35	1050	900	0.6	250	417	60	40	360	35	Purged with nitrogen	417	Web
5	D	45	940	815	0.6	280	421	67	40	360	30	Air	420	Web
6	E	35	970	830	0.6	295	444	66	38	355	30	Air	440	Web
7	F	40	980	850	0.6	275	420	65	40	350	35	Air	421	Web
8	G	35	1000	900	0.6	297	433	69	39	350	35	Air	440	Web
9	H	35	980	850	0.3	300	448	67	38	330	20	Purged with nitrogen	440	Web
10	H	20	980	840	0.6	304	442	69	39	350	30	Purged with nitrogen	310	Welded portion
11	H	35	980	840	2.5	351	495	71	32	350	30	Air	505	Web
12	I	35	990	880	0.6	305	440	69	38	360	35	Purged with nitrogen	450	Web
13	J	35	970	850	0.6	280	432	65	38	370	35	Air	420	Web
14	K	35	1050	910	0.6	321	450	71	34	360	30	Air	325	Welded portion
15	L	35	980	820	0.6	330	461	72	33	330	20	Purged with nitrogen	333	Welded portion
16	M	35	970	820	0.6	280	443	63	36	355	30	Air	385	Welded portion
17	N	35	980	830	0.6	299	430	70	36	350	25	Air	346	Welded portion
18	Q	35	980	830	0.6	297	418	71	39	350	30	Air	370	Welded portion

Note: Column with underline is out of the scope of the present invention

Table 3

Steel mark	Components (mass%)										Remarks		
	C	Si	Mn	P	S	Al	Cr	N	Cu	Ni	V	Mo	C+N
AA	0.0046	0.20	0.23	0.029	0.004	0.010	9.44	0.0060	0.52	0.18	0.07	-	0.0106 Example
BB	0.0037	0.21	0.26	0.024	0.005	0.008	9.97	0.0068	0.41	0.30	0.05	-	0.0105 Example
CC	0.0104	0.19	0.06	0.025	0.008	0.008	8.03	0.0025	0.45	0.20	0.03	-	0.0129 Example
DD	0.0044	0.21	0.30	0.028	0.006	0.021	9.40	0.0040	0.66	0.20	0.01	-	0.0084 Example
EE	0.0048	0.30	0.26	0.032	0.006	0.010	9.14	0.0045	0.35	0.14	0.18	-	0.0093 Example
FF	0.0059	0.10	0.27	0.011	0.001	0.001	8.99	0.0040	0.45	0.20	0.09	-	0.0099 Example
GG	0.0066	0.22	0.22	0.014	0.003	0.008	8.80	0.0036	0.40	0.20	0.06	-	0.0102 Example
HH	0.0094	0.45	0.14	0.029	0.005	0.010	9.40	0.0056	0.30	0.03	0.10	-	0.0150 Example
II	0.0051	0.21	0.24	0.030	0.004	0.012	9.12	0.0047	0.05	0.19	0.04	0.31	0.0098 Example
JJ	0.0054	0.20	0.26	0.028	0.005	0.013	9.22	0.0039	0.28	0.20	0.05	0.08	0.0093 Comparative example
KK	<u>0.0110</u>	0.22	0.25	0.035	0.007	0.009	8.89	0.0044	0.33	0.21	0.03	-	<u>0.154</u> Comparative example
LL	0.0058	0.22	0.26	0.035	0.005	0.009	9.10	<u>0.0105</u>	0.45	0.20	0.04	-	<u>0.0163</u> Comparative example
MM	0.0094	0.30	0.14	0.030	0.006	0.012	9.30	0.0066	0.31	0.01	0.03	-	<u>0.0160</u> Comparative example
NN	0.0090	0.20	0.23	0.029	0.005	0.012	9.25	0.0045	<u>1.20</u>	0.20	0.05	-	0.0135 Comparative example
OO	0.0088	0.24	0.22	0.028	0.006	0.011	9.33	0.0052	0.40	0.30	<u>0.30</u>	-	0.0140 Comparative example
PP	0.0065	0.23	<u>0.51</u>	0.033	0.005	0.013	8.95	0.0059	0.32	0.20	0.08	-	0.0124 Comparative example

Note: Column with underline is out of the scope of the present invention

Table 4

No.	Steel mark	Hot-rolling conditions				Steel sheet characteristics of edge portion (L direction, JIS No. 5)				Steel sheet characteristics of width portion (L direction, JIS No. 5)				Remarks	
		Roughing reduction in thickness at 6 th pass (%)	Finish rolling temperature (°C)	Coiling temperature (°C)	Average cooling rate from 800 to 400°C (°C/min)	0.2% proof stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	Elongation (%)	0.2% proof stress (MPa)	Tensile strength (MPa)	Yield ratio (%)	Elongation (%)		
21	AA	35	1000	850	500	0.3	256	414	62	42	245	404	61	44	Example
22	AA	35	980	830	410	0.4	298	444	67	42	255	405	63	45	Example
23	BB	30	980	820	450	1.0	255	410	62	45	236	400	59	48	Example
24	CC	35	1050	900	550	0.3	270	420	64	43	248	415	60	45	Example
25	DD	45	940	815	500	0.5	277	422	66	41	270	418	65	42	Example
26	EE	35	970	830	480	0.4	298	450	66	40	286	440	65	43	Example
27	FF	40	980	850	500	0.3	280	438	64	42	270	414	65	44	Example
28	GG	35	1000	880	530	0.4	288	434	66	40	280	430	65	42	Example
29	HH	35	980	840	560	0.5	298	446	67	40	280	443	63	43	Example
30	HH	35	980	840	510	2.5	350	490	71	31	303	445	68	34	Comp. Ex
31	HH	35	980	840	350	13.0	450	602	75	25	352	504	70	34	Comp. Ex
32	II	35	1000	880	540	0.4	320	447	72	40	280	430	65	42	Example
33	JJ	35	980	830	500	0.3	285	435	66	40	265	422	63	42	Example
34	KK	35	1050	910	500	0.4	380	522	73	31	332	472	70	35	Comp. Ex
35	LL	35	970	840	510	0.3	368	510	72	33	303	480	63	37	Comp. Ex
36	MM	35	980	830	480	0.3	377	515	73	29	333	455	73	34	Comp. Ex
37	NN	35	980	820	450	0.4	390	536	73	31	350	480	73	35	Comp. Ex
38	OO	35	990	830	520	0.4	367	502	73	30	325	460	71	37	Comp. Ex
39	PP	35	980	830	490	0.5	359	505	71	31	330	460	72	38	Comp. Ex

Note: Column with underline is out of the scope of the present invention